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EXCHANGE FROM THE EARTH'S SURFACE  
THROUGH THE STRATOSPHERE Progress  
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## **Towards a Theory of Tropical/Midlatitude Mass Exchange from the Earth's Surface Through the Stratosphere**

Progress Report for Year One: 12/1/94 - 9/30/95

Grant Number: NAG 5 - 2789

UARS Guest Investigator Program, PI: Dana Hartley

### **I. Introduction**

The main focus of this work is to understand the dynamics of mass exchange between the tropics and the midlatitudes and to determine any links between tropospheric exchange and that in the stratosphere. We have approached this problem from two different perspectives. The first is aimed towards understanding the troposphere's role in inducing lower stratospheric tropical/midlatitude exchange. For this project we focus on observational analysis of the lower stratosphere to assess the key regions of transport in/out of the tropics and to what extent this transport is driven by tropospheric processes. The second approach is to determine the extent to which stratospheric processes influence the troposphere. In this project we are performing potential vorticity (PV) inversions to assess the winds induced near the tropopause when the stratospheric polar vortex is displaced equatorward. These are each discussed in more detail in the subsections below. Also, we have organized a session on Tropical/Midlatitude Interaction and Transport at the Fall AGU where we will be showing our latest results.

### **II. Tropospheric Influence on the Stratospheric Tropical/Midlatitude Exchange**

The first step towards the assessment of this influence is to observationally determine the preferred longitudinal regions of tropical/midlatitude exchange in the stratosphere. To do this we used the aerosol data from the CLAES instrument. The data have not been as easy to access as we had hoped. The time delays from the DAAC can be unpredictable. Sometimes the turn around is overnight, but at times it takes days. We have now received the 3AT data on CD-ROM, but we have been predominately making use of the 3AL data, so we still must rely on the DAAC. It would be preferential to have the 3B data released so that we know we are working with consistently gridded data sets. Both 3AT and 3AL data must be interpolated to a grid for analysis, and thus, there is the potential for differences among the analyses of different investigators. We used an asymptotic Fourier transform (Cao, 1995) with 3AT data. However, this technique requires a subset of 3-5 days to obtain a the midpoint time, and we felt this substantially diminished the number of consecutive days for the synoptic analyses we want to perform. Thus, we have chosen to work with the 3AL data which is significantly closer to being spatially gridded. We use a linear interpolation to complete the gridding. The only issue we then run into is the time, since each 3AL grid is made up of snap shots throughout the day. However, a daily picture is still much more informative for examining transient synoptic scale patterns than the more coarse monthly picture previously used for such analysis from SAGE (Trepte et al., 1993).

The next issue is the vertical level to use in assessing the horizontal transport. The CLAES aerosol data are reported in extinction ( $\text{km}^{-1}$ ). However, these units are not conserved in vertical displacement. Thus, we convert the units to a mixing ratio (Lambert et al., 1993) and then interpolate the mixing ratio to isentropic surfaces. Figure 2.1 shows the aerosol mixing ratio distribution for February 19, 1992  $925 \text{ cm}^{-1}$  at 500K (approx. 20km). This is near the tropical maximum in aerosol extinction. In the figure we see a strong delineation between the tropics and midlatitudes with some movement of tropical air northward on the western edge of the Pacific. Now if we look at Figure 2.2, the same plot but on the 425K surface, it is clear that there is no longer a strong delineation, presumably due to mixing. Note that in Trepte et al. (1993) they show observations of a strong delineation on the 425K surface, but these observations were from right after the Mt. Pinatubo eruption.

Our next step is to calculate the meridional mass fluxes from the tropics as done by Hartley and Black (1995) for the troposphere. The diagnostics are necessary to extract signatures of net transport from the observations. We will combine the mixing ratio data with winds taken from UKMO and/or STRATAN to make these calculations. From idealized tracer simulations in the CCM2, we expect that synoptic wave activity is an important mechanism. This is illustrated in Figure 2.3, showing results from a model simulation (CCM2) with an initial tracer distribution of constant mixing ratio in the Southern Hemisphere and zero in the Northern Hemisphere. These figures show the simulation 3 and 4 weeks into the run. Tongues of tracer are carried into the Northern Hemisphere by passing synoptic waves and break in midlatitudes.

### **III. Stratospheric Influence on the Tropospheric Tropical/Midlatitude Exchange**

To assess the influence of the stratosphere on tropical/midlatitude exchange in the troposphere, we are first focusing on particular episodes during which tongues of upper stratospheric tropical air are observed to be drawn poleward as the polar vortex is displaced equatorward (see Figures 3.2 and 3.3). Evidence for this entrainment of tropical air into midlatitudes by the displaced vortex has been observed and confirmed in studies of profiles of certain trace gases and of potential vorticity (PV) (Randel et al, 1993; Manney et al, 1994). However, it not known whether the displaced vortex in the middle to upper stratosphere influences the exchange of tropical/midlatitude air in the lower stratosphere and troposphere. This displacement may induce an equatorward movement of the tropospheric waveguide and, therefore, allow more ready interaction between synoptic eddies and the tropics. To determine whether or not a dynamical connection exists between the vortex displacement and this mass exchange, we apply a powerful diagnostic tool, PV inversion, to deduce the anomalous flows in the lower stratosphere and upper troposphere associated with this equatorward movement of the polar vortex (Hoskins et al, 1985).

As a first estimate of this, we performed a simple 2D experiment by calculating the Ertel's PV distribution from the wind data of Newell et al. (1972). We then performed an elementary simulation of vortex displacement by simply transposing high PV polar air into the lower latitudes. The anomalous PV was then inverted to determine the resultant flows associated with the presence of this high PV air at lower latitudes.

Our results, plotted in Figure 3.1, show that PV displaced from high to low latitudes induces anomalous winds extending all the way down to the tropopause. In Figure 3.1(a), we transposed the entire stratospheric PV at 70N to 40N while in Figure 3.1(b), we limited the PV anomaly at 40N to just the upper stratosphere. The former shows strong anomalous winds forming near the tropopause while the latter shows an anomalous wind regime that decays away from the PV source anomaly but is nevertheless still significant near the tropopause.

Our next step is to perform full 3D PV inversions on actual episodes of polar vortex displacement. For this, we use the UKMO assimilated wind, temperature, and height fields. We have first chosen the northern hemisphere winter of 1992-1993 and have selected a particular wave breaking event (1 Jan 1993) for our initial study. We use UARS CLAES observations of N<sub>2</sub>O and aerosols to supplement our PV analysis. Figure 3.2 shows the upper stratospheric profile of Ertel's PV, illustrating two prominent wavebreaking events over Greenland and the Siberian region, and the northward entrainment of low PV tropical air over the Atlantic. Figure 3.3 complements this PV plot by showing UARS observations of N<sub>2</sub>O on the same 850K isentropic surface and demonstrating this same entrainment of tropical air into the midlatitudes on this particular day. Thus, the wave breaking event of 1 Jan 1993 is a suitable choice for performing this 3D PV inversion.

We are in the process of applying a 3D PV inversion on this episode to determine the induced wind fields near the tropopause. We are first using the quasigeostrophic (QG) form of PV because of its linearity. This allows the hemispheric inversion to converge more readily and makes it simple to evaluate (Davis, 1992 and Davis, personal communications). The QGPV is given by:

$$q = \nabla^2 \Psi + f_0 + \beta(y - y_0) + \frac{f_0^2}{r} \frac{\partial}{\partial \pi} \left( \frac{r}{S} \frac{\partial \Psi}{\partial \pi} \right)$$

The inversion routine that we are using has been kindly provided by Dr. Christopher Davis of NCAR. The inverted winds will be overlayed on the climatological waveguide to see if the guide shifts equatorward thereby promoting increased wave activity near the tropics. We will then compare our calculated flow field with observed UARS data of passive tracers such as N<sub>2</sub>O and aerosols to see if there is evidence of increased mixing in the lower stratosphere during these times in association with variations in the waveguide. These results will be presented at the 1995 fall meeting of the AGU. Our next step is to apply the inversion to all the wave breaking events of the winter of 1992-1993.

Depending on how informative the QGPV is, the next goal may be to perform inversions of Ertel's PV for such wave breaking events to discern any additional patterns that may help us understand what role the stratosphere has in the tropical/midlatitude exchange near the tropopause.



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UARS CLAES Aerosol 3AL

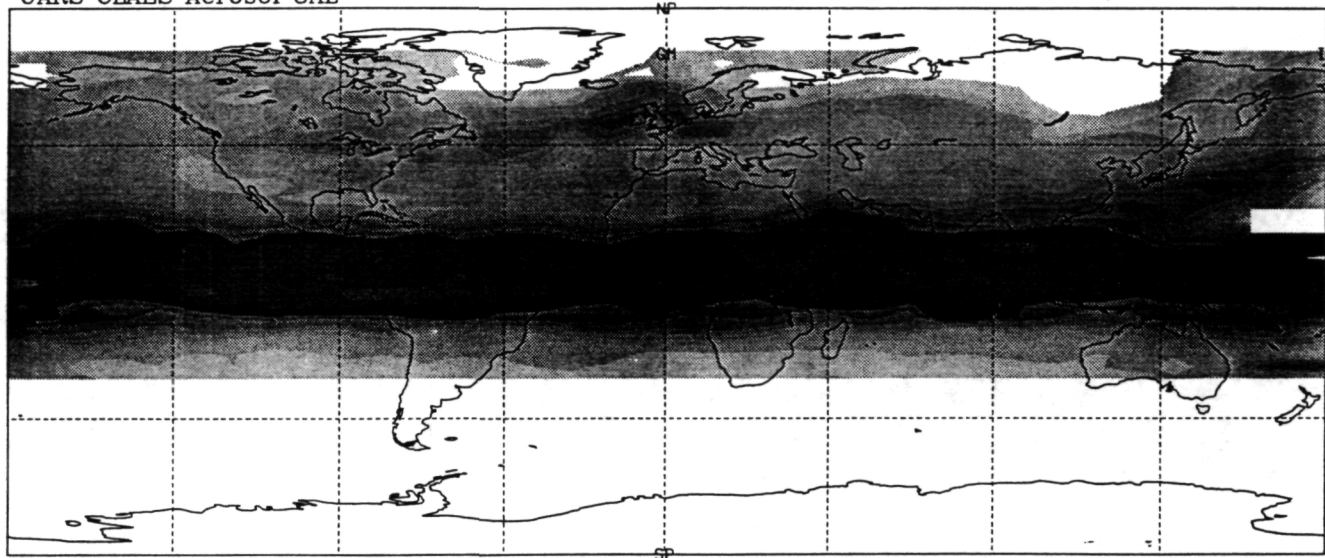
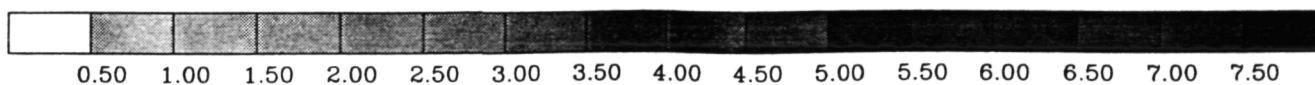
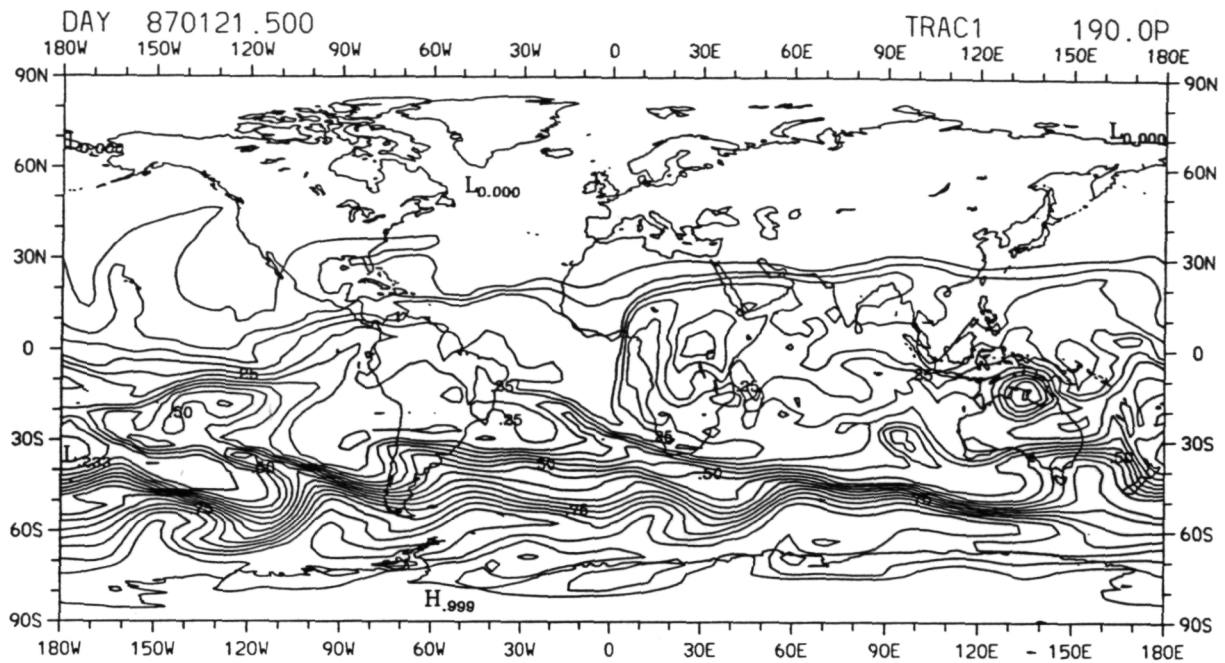


Figure 2.1. CLAES 3AL Aerosol at 925 cm-1 on Feb. 19, 1992 on the 500 K surface.





CASE: cfc002 Interhemispheric Exchange Study



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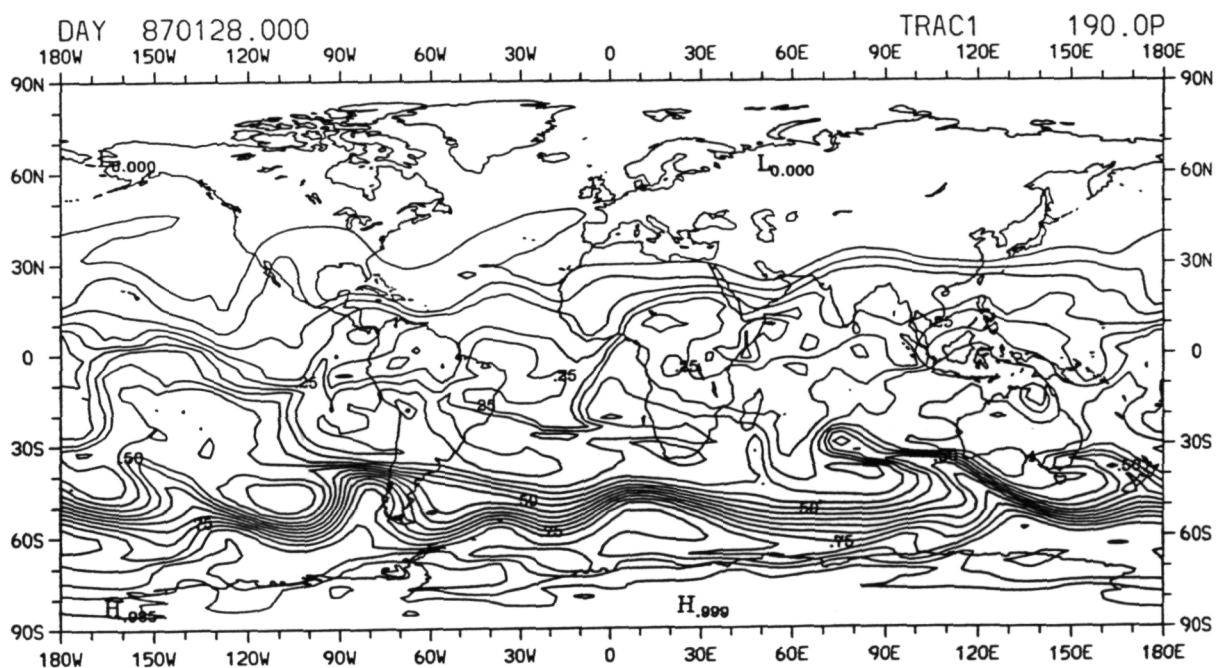


Figure 2.3. Idealized tracer simulation in the CCM2 on the 200mb surface.

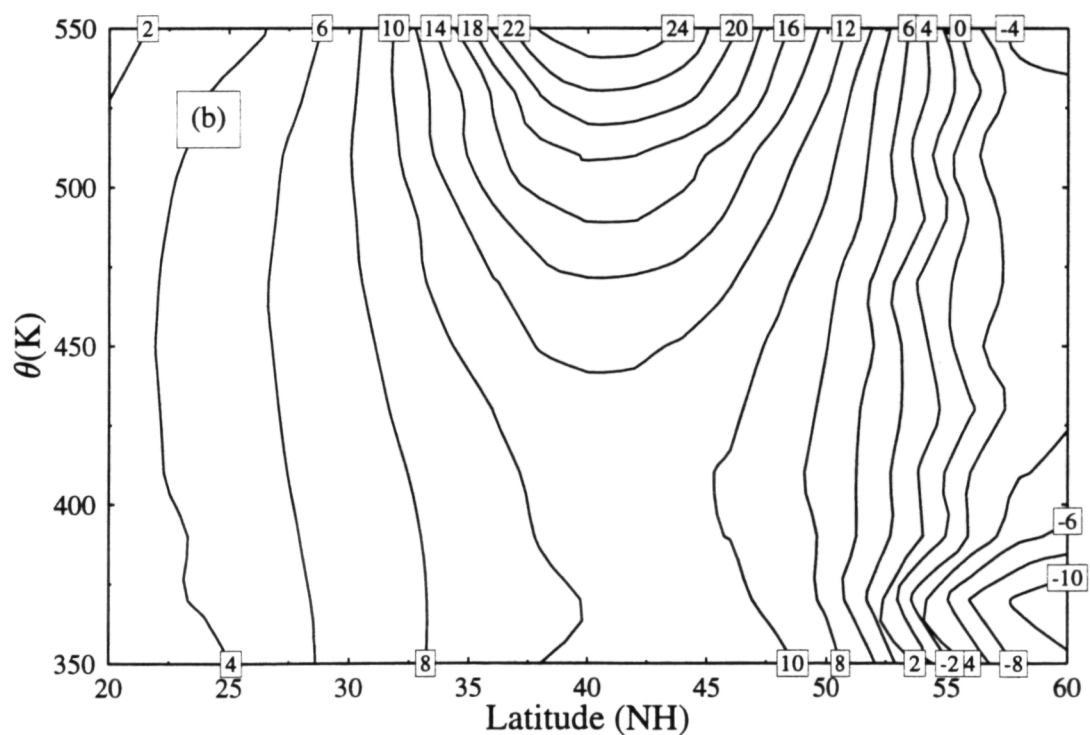
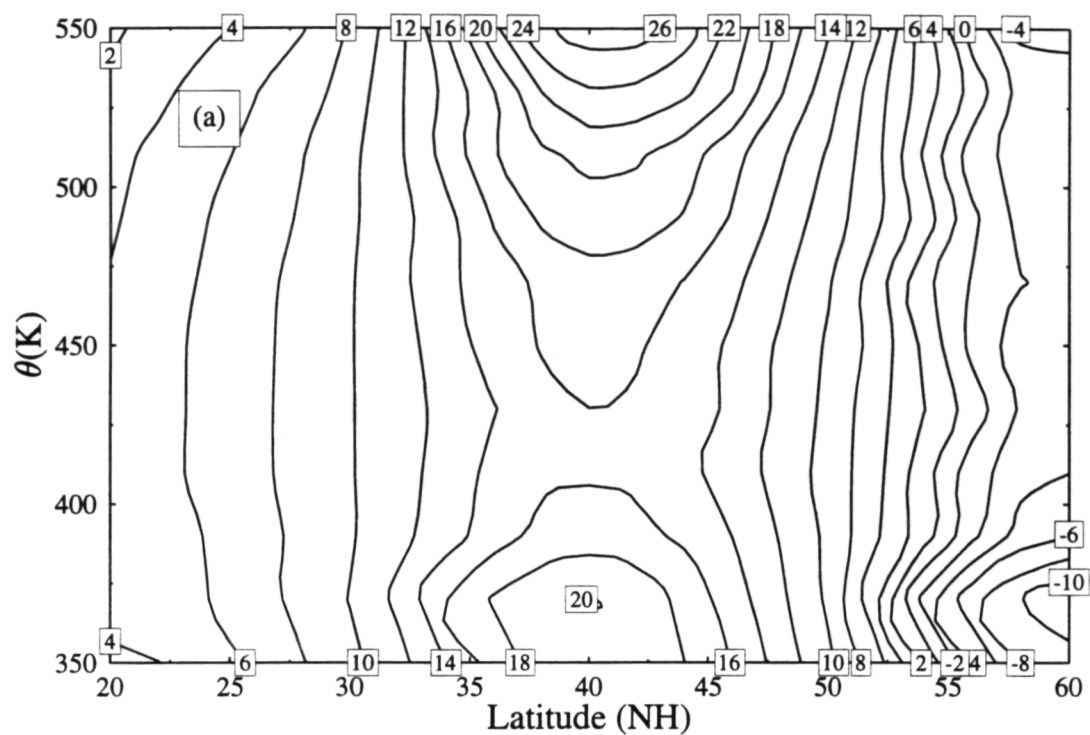
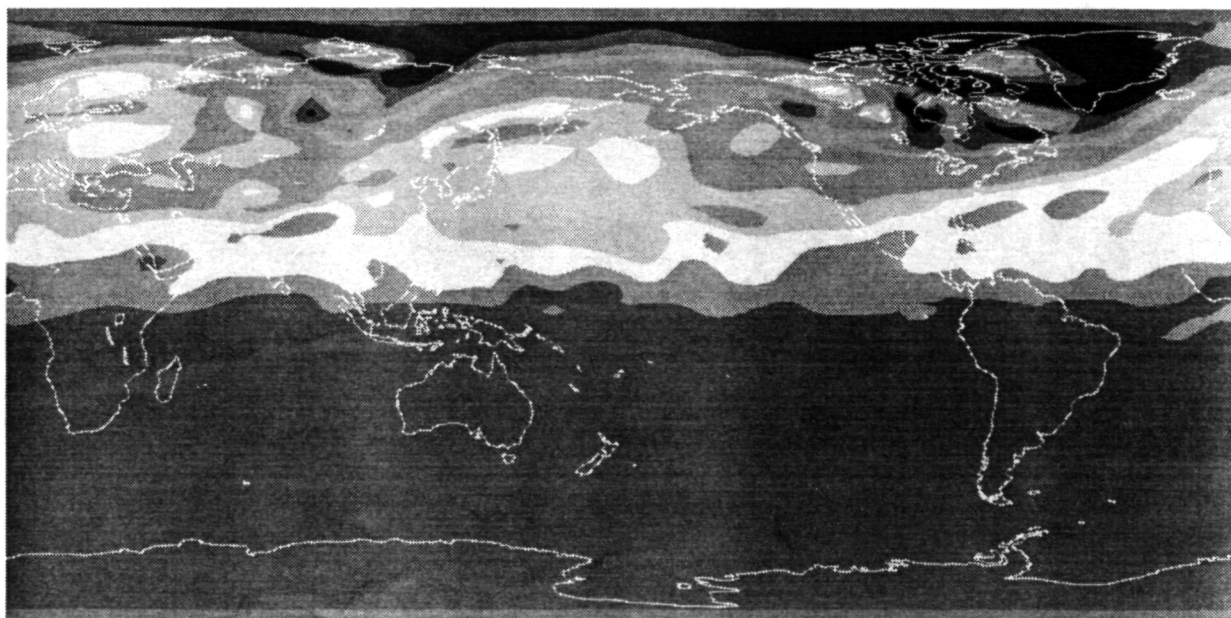


Figure 3.1 Inverted zonal winds (m/sec) associated with high PV polar vortex air displaced from 70N to 40N. (a) Full vertical PV displacement from 600K down to the tropopause and (b) partial displacement of high PV air from 600K to 450K.

Potential Vorticity (PVU)

UARS Day 478 (850K)



CONTOUR FROM -300 TO 800 BY 100

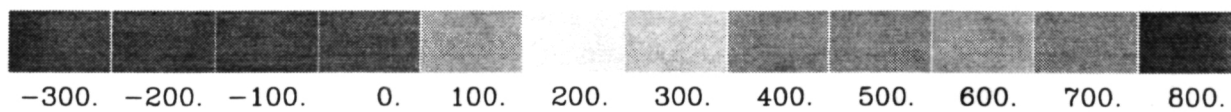


Figure 3.2 Plot of PV during wave breaking event. Note entrainment of tropical air over Atlantic.

N<sub>2</sub>O Mixing Ratio (ppbv)

(850K) UARS day 478

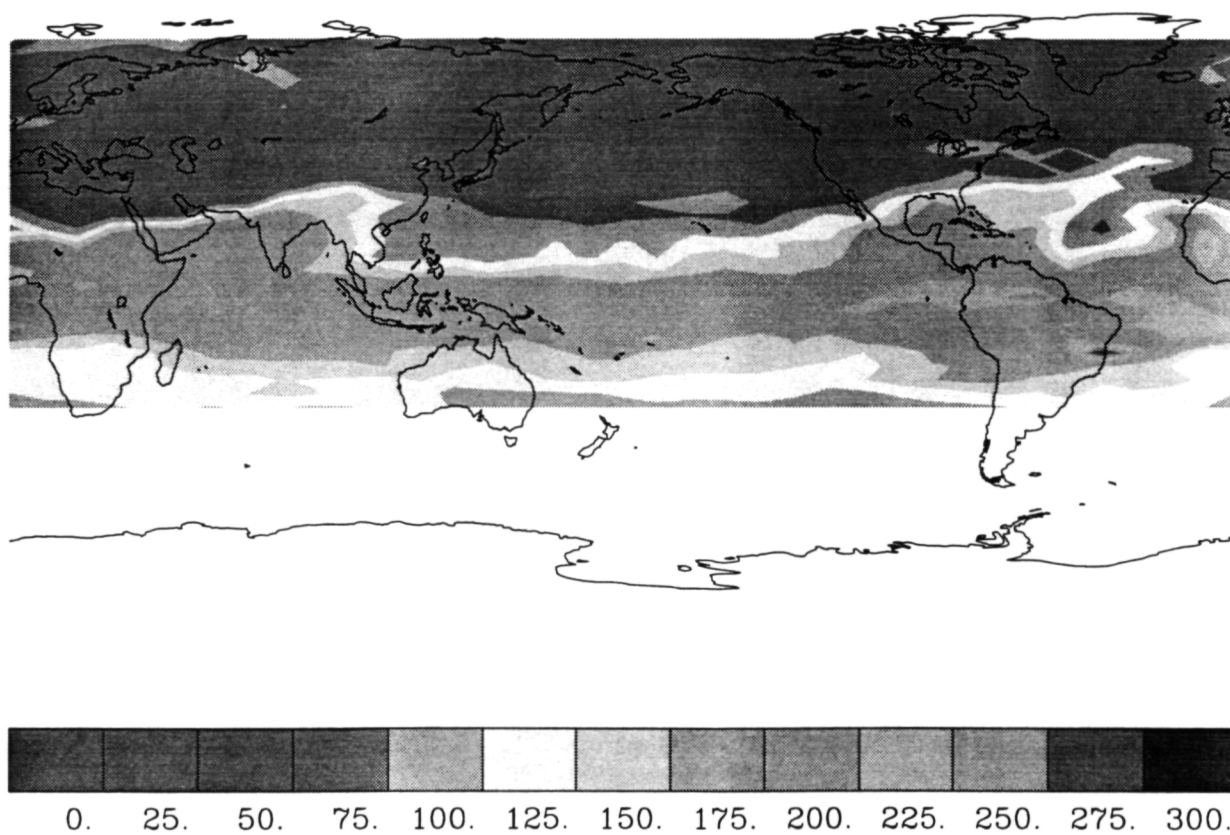


Figure 3.3 Plot of N<sub>2</sub>O during wave breaking event. Note entrainment of tropical air over Atlantic.